Dust in the divertor sheath: a problem or a possible solution to a problem?

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Long-pulse machines like ITER (or steady-state like DEMO) must rely on a nearly perfect balance between erosion and redeposition to avoid point failure on the plasma-facing components. In this regard, the role of solid particulates or dust (created from the wall materials by the plasma-material interaction) in affecting this required local balance between erosion and redeposition has recently emerged. Indeed, while impurity neutrals can be ionized near the wall and hence promptly sent back to the wall, in present short-pulse machines solid dust particles can traverse long distances in the plasma chamber [1]. The dust particles either stay as dust as plentifully collected on all existing short-pulse tokamaks (causing safety issues for fusion reactors) or redeposit non-locally, which can lead to large net local erosion.

In this work, we will present results on dust transport in the magnetized sheath near the divertor plate for micron-sized dust. We consider conditions relevant to present short-pulse tokamak machines as well as conditions for long-pulse ITER/DEMO reactors. We solve the dust charging equation, the dust equation of motion and the equations for dust heating and mass loss in the magnetized sheath. We present parametric studies changing the divertor plasma conditions and the angle of the equilibrium magnetic field relative to the wall. Our main result is that, for conditions relavant to DEMO, the stronger heat flux to the wall severely limits the dust survivability and mobility. Consequently, a single dust grain tends to redeposit the material locally, in contrast to what happens in short-pulse machines. We discuss the implications of this result for the divertor plates of long-pulse fusion reactors [2].

With the insight gained for sheath dust transport simulations, we present two fusion technology solutions to DEMO PFC based on externally introduced solid particulates. These include the dust patch and the dust shield [3] concepts. The dust patch represents a mitigation strategy where engineered solid dust particles are injected in the chamber to patch areas of net erosion at runtime. In the dust shield concept, tungsten dust particles (of certain size) are suspended above the divertor by the sheath electric field and are circulated poloidally by the sheath plasma flow. Thus, dust particles can be injected at one end of the divertor and be collected at the other end before they melt. During their transit across the divertor, they form a circulating shield that provides the primary heat exhaust. Essentially, the dust shield concept replaces the liquid metal wall in the liquid metal PFC concept by solid particulate.

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